Technical Evaluation Report

Part B – Heat Transfer and Cooling in Propulsion and Power Systems

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Summary

The purpose of the meeting was to give an overview on the latest results of heat transfer and cooling in propulsion and powersystems and to enable the exchange between experts from universities, research organisations and industry. This objective has been achieved in terms of gas turbines. A large number of papers has been presented dealing with heat transfer in gas turbines and here the most discussed part is still the cooled airfoil. The precise knowledge of heat transfer is a precondition for proper cooling and hence improved effectiviness of the gas turbine. The prediction of heat transfer by analytical means remains difficult. Further research is necessary.

In terms of non gas turbine applications, e.g. heat transfer and cooling in internal combustion engines or rockets the contribution was very low.
Future symposia should either concentrate on heat transfer in gas turbine or take measures to make the event more attractive also for other power systems. However since there is no clear synergy effect between gas turbines and other power systems it is recommanded to limit future symposia on gas turbines.

Introduction

I have the honour to summarize and to comment the part B of the symposium “Advanced Flow Structure”, which is entitled “Heat Transfer and Cooling in Propulsion and Power Systems” and my first comment concerns this title.

It should include gas turbine for aero and industrial application, internal combustion engines, rockets and others but the agenda did not reflect this variety of applications.

At the end, after several papers have been withdrawn, only two contributions came from the internal combustion engine side and two from other areas. I had the impression that also the audience have been distributed in a similar way, most of them belong to the long existing “heat transfer in gas turbines” community.

So in reality this symposium was the continuation of the former AGARD conferences on “Heat Transfer and Cooling in Gas Turbines”.

My second comment concerns the question, whether this intensive concentration on gas turbine cooling is justified. - Is it still so important? The answer was given by one of the key note speakers. Gas turbine cooling is a key technology to develop the gas turbine to lower fuel consumption and in terms of military application to higher thrust to weight ratios.

In terms of turbine inlet temperature this means that a gap of roughly 500 K of temperature increase is open for the next decades before stochiometric temperatures are reached. Interims of turbine cooling, this means new more effective cooling configuration must be developed toclose the gap. This forecast is based on the experience from the past where turbine inlet temperatures have been increased over the past 30 – 40 years by 500 K. It is not primarily driven by our customers.

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Of course the customers want to have engines with low fuel consumption but they are primarily interested in low cost, high reliable engines. This drives a further trend: Increasingly engines are designed by considering the real geometric and real physical conditions to improve the prediction of lifetime, simplification or averaging should be avoided, 2D calculations must be replaced by 3D methods to regard also secondary effects.

Many engine parts which have been formerly designed using simplified methods will be analysed in future by 3D Methods. In terms of heat transfer this means, we have to know the 3D boundary conditions and there are many examples where these data are not available.

I would like to give an example:
The design of the cooling channel of a cooled turbine blade today is based on a 1D analysis. Before we start to use 3D analytical tools several activities must be performed: A 3D CFD code must be developed which is able to calculate the local heat transfer coefficient under consideration of ribs and pins, this code must be validated on experimental results.

It is convenient to perform this validation in steps, first to compare simple configuration neglecting rotation and stepwise to increase the complexity. So an increasing variety of experimental test on heat transfer and cooling must be available.

It is my task as technical evaluator to judge whether the combustion of the meeting are reflecting these demands. Therefore let me shortly go through the agenda and discuss the various contributions.

<u>Evaluation</u>

Let me start with a short statistical overview shown in the figures 1 to 4.
The agenda has announced 40 papers, from which 32 have been presented, the remainder has been withdrawn.
The distribution among the nations giving presentations is shown in fig 1. Most participants came from Europe, only four from US.
As already mentioned the majority of the presentations dealt with gas turbines, other power systems like internal combustion engines and rockets have contributed only five papers. From the gas turbine papers on the other hand 66% are discussing the heat transfer outside and inside turbine airfoils only few are dealing with combustors. So a clear focus of the symposium was directed on highly heat loaded cooled turbine airfoils.

The presentations has been distributed in 7 sessions
- Experimental techniques and procedures
- Geometry effects on heat transfer
- Flow effects and flow structure
- Advanced cooling concepts / Heat Transfer
- Modeling and design tools
- Numerical simulation of heat flux
- Unsteady heat flux

In my view this is a reasonable arrangement.
However, since the authors did not know to which session they would be arranged in some cases, an alternative classification of the papers seemed to be convenient.

Session 1: Experimental Techniques and Procedures

The papers presented in this session dealt with measurement techniques, however they differ from the subsequent papers only by the degree of description of these techniques. The methods themselves are those used later and also the subjects of investigation are widely the same, the heat transfer and the film cooling effectiveness of the outer surface of a film

cooled airfoil and the enhancement of the cooling by geometrical changes of cooling passages.

There are only two exceptions, two presentations dealt with the heat transfer in the cylinder of internal combustion engine, using thin film gauges and showing the time resolved influence of engine conditions thereby discovering some transient effect which today can not be interpreted.

The most common method to perform the described measurement on airfoils is the transient liquid crystal technique. This technique allows very close local resolution, what is the aim of many subsequent papers. Models need to have optical access and must be made from bed conductive material, a combination for which perspex is the best selection.

Miglori has this method used to investigate the ribbed inner surface of a Low Pressure Turbine blade, Sargison demonstrated that this method can also be used for a real turbine NGV. This facility is able to measure all effects which must be considered designing film cooled NGV, film efficiency and heat transfer coefficient, the drag coefficient of the film cooling holes as well as the aerodynamic loss caused by the introduction of film cooling.

Ireland proposed a new method to investigate the heat transfer coefficient condition in complex cooling configuration where it is not possible to work with liquid crystals. This methods delivers indeed only averaged heat transfer coefficients however it is suitable for the quick assessment of a large number of configuration since it is less time consuming.

Session II untitled “Geometry Effects on Heat Transfer” covered 6 pages.

All papers presented are discussing heat transfer of film cooled surfaces either airfoils or the effusion cooled combustor wall. The aim of all papers has been to provide the designer with information how to better control heat transfer by geometrical changes. Such effects have been the curvature of the surface, number of rows of holes, spacing of holes in both orientations and hole geometry.

Typically most of the papers have been presented by or together with authors from industry . My assessment is that these papers are most valuable to make the design of a gas turbine more reliable.

Of course the results are only as good as the measurement techniques is which was demonstrated by a paper of Polanka in terms of the application of heat flux gauges.

In session III – <u>“Flow effects and flow structure”</u> – more fundamental effects have been investigated.

The contribution of Bataille is a complement to session II:
The effusion cooling is replaced by a porous wall, which improves the cooling characteristics, but with limited application to real engine configuration due to the danger of clogging of the pores.

The fundamental flow and heat transfer conditions inside the rotating channel of a film cooled turbine blade have been investigated by Elfert.
While these both papers gave a more qualitative overview the subsequent papers of de Wolf and of Gillespie provide quantitative results:
De Wolf determinated the heat transfer on advanced high lift Low Pressure Turbine airfoils where large separations appear, Gillespie investigated the influence of rib height on heat transfer in cooling channels thereby using the same cooling channel and again the transient liquid crystal technique as in paper 4.

These papers can be classified in the category: Provision of a database and are therefore useful and necessary.

The session IV – "Advanced cooling concepts and heat management"– was a very heterogeneous group. This is a good example that it makes only sense to arrange contribution with very different content in one group if synergy effects are available.

Also in this session: The paper of Rowbury is interesting because it described the systematic process how to obtain a comprehensive database for the validation of 3D- CFD-calculation in a rotating multipass cooling system. The experimental models used became progressively more realistic starting with enlarged non rotating channels over simplified rotating channels up to an engine representative configuration which was rotated on a new RR-rig. This was an EU funded project, most partners in the project have used the database to validate their own CFD code.

The session V – "Modelling and design tools" –

covered only two contributions, however interesting ones.

The paper of Son is an example for the importance of consideration of local effects. It showed that in the case of a complex cooling configuration the higher local resolution opens the potential for improved cooling conditions.

The paper of Brisset was an overview which analytical method will be used at Snecma for the design of a high pressure turbine airfoils. 3D CFD methods are increasingly used. The validation of the models remains one of greatest challenges.

The two last sessions (session VI and VII) dealt with the numerical simulation of heat transfer, applied on various examples. A very comprehensive study has been performed by Martelli on a turbine stage.
He tested two different codes, one structured and another one unstructured. He investigated 5 different turbulent models and he carried out steady state as well as unsteady calculations. His own statement was at the end: Transition remains to be a black box.

Kulisa, who introduced a new thermal turbulence model, came to a similar result, also in this case the heat transfer in the transition region was not reproduced satisfactorily.

T. Arts investigated the rib roughened square duct representative for an airfoil cooling channel, a very simple geometry. Although the calculated flow field agreed well with experiments, the heat flux prediction remained difficult. Better thermal turbulence modelling could improve the situation.

Probably the correct determination of the detailed flowfield combined with an improved thermal turbulence model is a precondition for a successful modeling of heat transfer. Detailed flowfield measurements are necessary and the paper of Barigozzi seems to be a very useful contribution to close this gap. It provides the database for a film cooled nozzle.

(S. 9)
Although CFD methods are somewhat uncertain in terms of heat transfer they are widely used at universities, research institutes and industry. Typically the calculation of the fluid or gaseous domain must be coupled with structural temperature calculations.
This can be done by an iterative approach, as done by Balland, by a conjugated approach, example given by Bohn or by Luff or by the introduction of virtual boundary layer surfaces as done by Bock.

So far my comments on the various contributions. Overall it was a very comprehensive collection and reflecting the demands of gas turbine cooling.

<u>Conclusions</u>

The last AGARD Conference on Heat Transfer and Cooling took place in 1992. Have we made a progress since that time?

If I compare the agenda of the AGARD conference with the present agenda than on a first view nothing seems to be totally new and the progress seems to be very small. However a progress is made, continuously and in small steps and therefore hardly visible and with a dear shifting from average to local resolution.

Progress is made in terms of measurement technique – e.g. the liquid crystal technique was in 1992 new – today it is a widely used standard technique. Progress is also made in terms of the database, especially film cooling effectiveness data are available for a wide range of configurations.

It is started the attempt to calculate flow and heat transfer inside the cooling channel of a cooled turbine blade by 3D methods, the relevant data base will be elaborated. New cooling methods have been presented, the wall cooling concept for the turbine, effusion cooling for the combustor.

In terms of the numerical computation a progress is made in terms of handling, pre and post processing, grid generation is easier due to the use of unstuctured grids. It is no longer a problem to model complex geometries. However the proper calculation of the heat transfer is limited to simple geometric configuration.

<u>Recommendations</u>

My recommendation for the future is to proceed as before.

Of course it is desirable to have reliable 3D numerical methods available. Therefore a further effort is necessary to improve the methods itself one approach against is the improved simulation of turbulence.

It is necessary to identify the weakness of present modeling and for that a set of very detailed experiment result must be created.

In parallel it is also necessary to extend the database on typical 3D effects to support the engine design. Not only the heat transfer on the blade is important to know, also the heat transfer in the end wall region.

And heat transfer alone is not sufficient, flow measurements should complete the heat transfer. This is not new. This is the way the knowledge on heat transfer have been improved in the past and on this way should be further proceeded.

Before I end, a last comparison with the past AGARD conference:
The ratio of papers withdrawn for the present conference increase by a factor of 2. The number of participants has clearly decreased. The responsibles should consider how to make the conference more attractive.

Munich, 27.7.01 Burkhard Simon

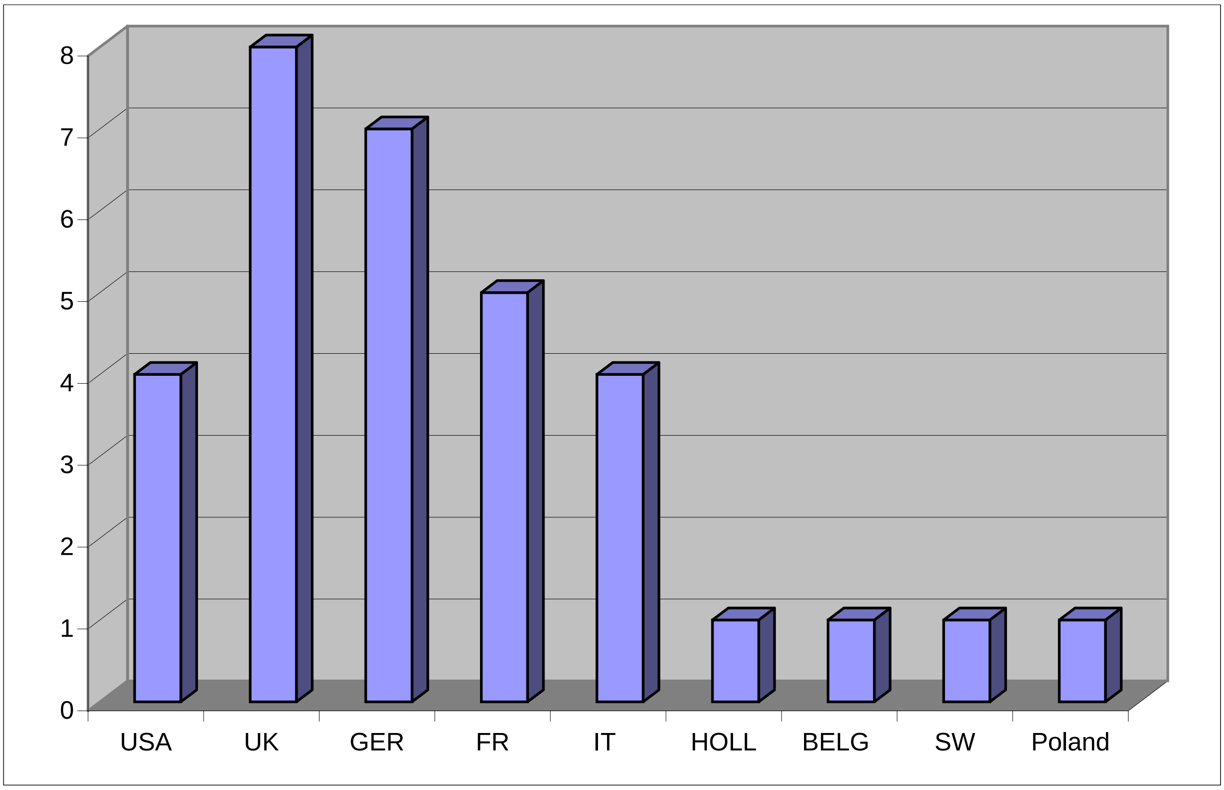

Fig. 1 Nationwide distribution among the presenters

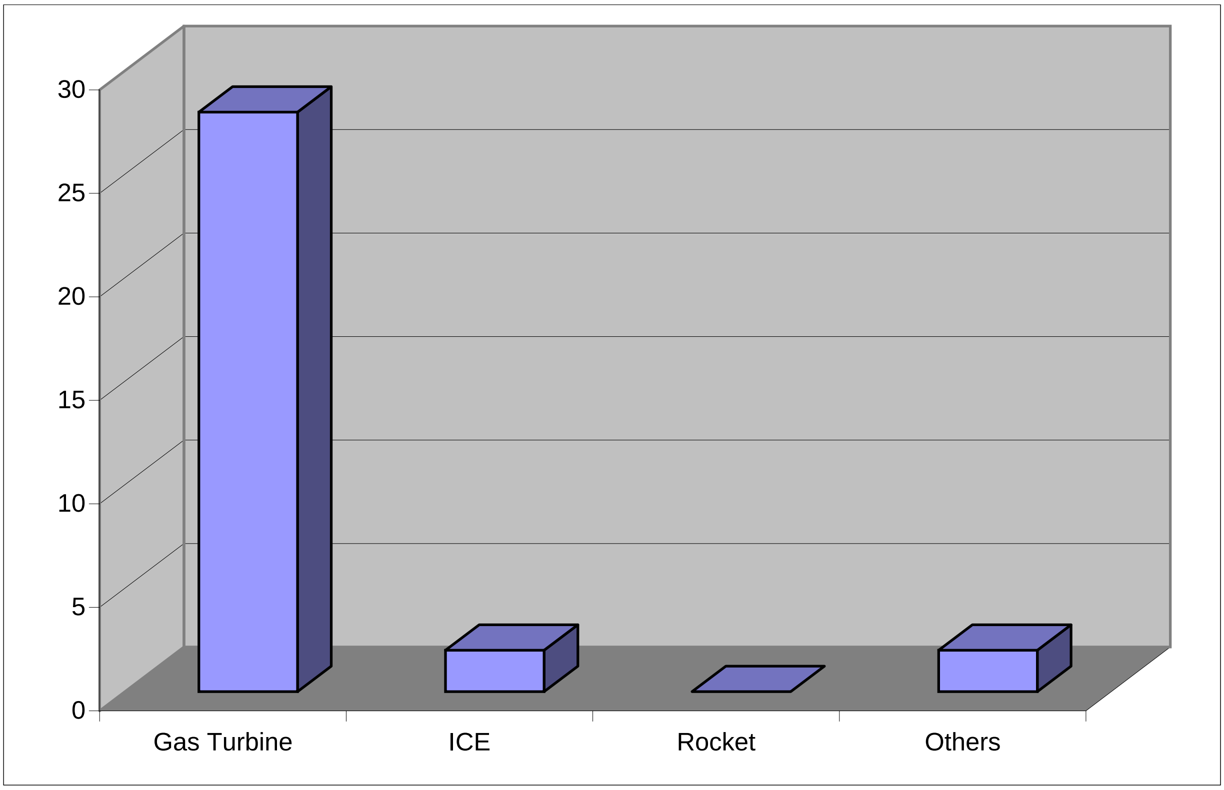

Fig. 2 Distibution among various power systems

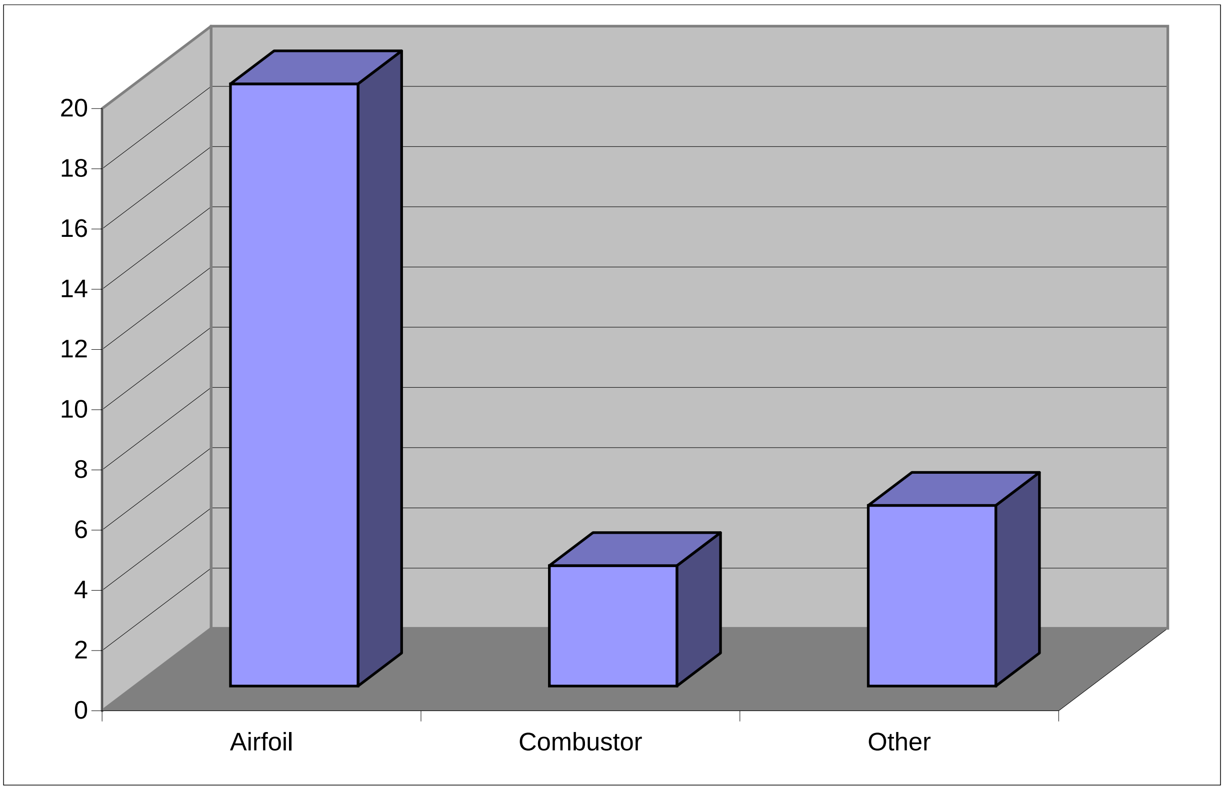

Fig. 3 Distribution among various components of gas turbines

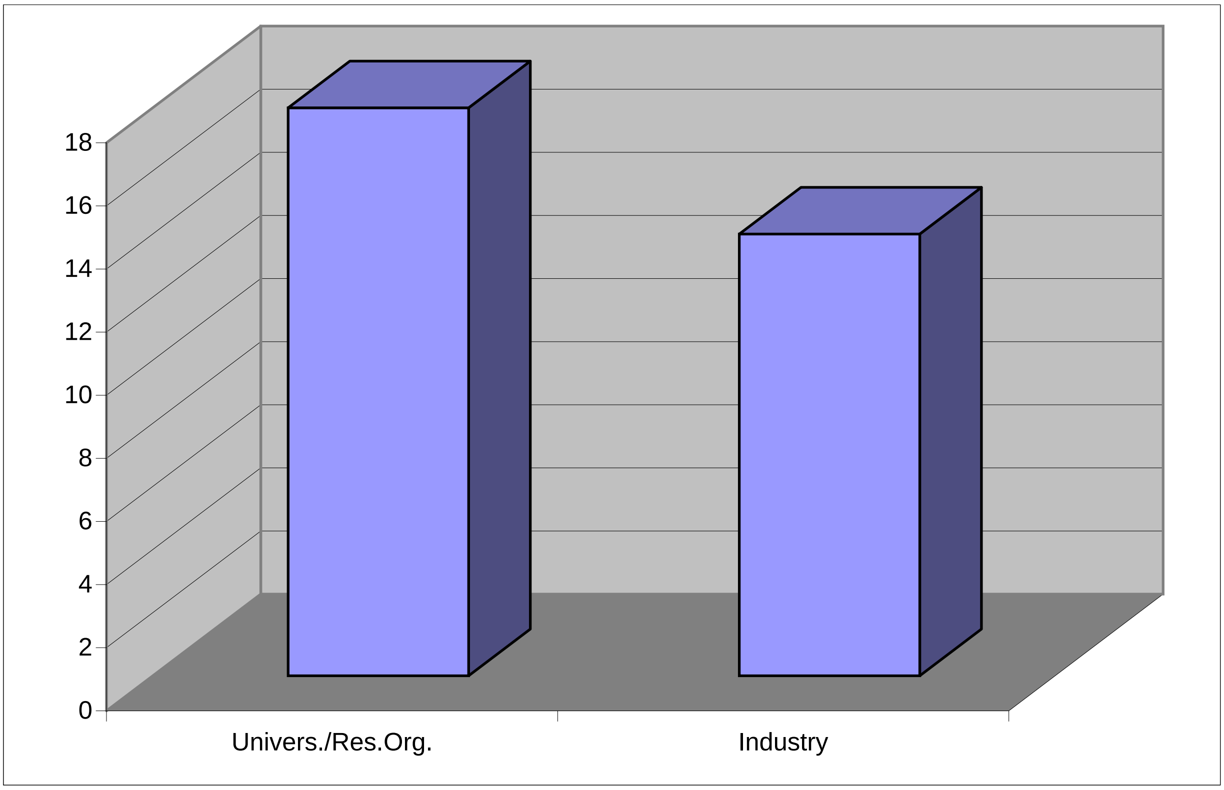

Fig. 4 Distribution among various organisations

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